HUMAN COMFORT AS A BASIS FOR CLASSIFYING WEATHER *

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The purpose of this paper is to attempt to classify the weather according to its bearing on human comfort. Usually, climates are described in terms of average and extreme conditions of such elements as temperature, vegetation of the region, or according to the altitude and latitude. In climatological literature we do not often find, however, that most interesting feature: The frequency and sequence of different weather types, and how these affect human comfort.

Human comfort as a basis of a classification will differ from mere temperature or humidity or wind or cloudiness or altitude or latitude inasmuch as a classification based on it depends directly on a combination of these factors rather than on any one of them. Hot dry weather can be borne better than hot damp weather.

In the classification given below, the factors of temperature, wind, sunshine, and evaporation form the basis.

A previous attempt was made by the writer to classify the weather according to combinations of the factors of temperature, sunshine, humidity, and winds. A scale was constructed by a simple arithmetical formula in which different combination were made and classified according to their effect on human comfort. This classification was applied to weather observations made at Worcester, Mass., and the result shown at the meeting of the American Meteorological Society at Toronto in December, 1921. The following note appeared in the Bulletin of the Society in April, 1922, page 63:

> An arbitrary scale of human discomfort was made from the various combinations of five classes of temperature, three of sunshine, two of wind, and three of humidity, and with this the daily weather at Worcester for the past three months was plotted. The preponderance of comfortable days in September and October stood in marked contrast to the numerous uncomfortable days in November and December. There was a change from the best (moderate, bright, quiet, and dry) on November 8 to the worst (cold, dull, windy, and damp) on the 9th.
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> *Discussion.*—The question was raised as to whether Arizona weather could be shown on such a scale. The answer was that it could, and that it would show that most days, say, at Tucson, Ariz., would be more comfortable than many of those experienced in Worcester in winter and summer.

Later, the classification was applied to data from Phoenix, Ariz., and the Phoenix chart showed a distinct trend toward ideal conditions in the months from November to April and rather uncomfortable conditions during the summer months.

However, the above scheme was abandoned upon the suggestion of Dr. C. F. Brooks, because marked irregularity in the curve overemphasized the relative comfort of successive days, thus indicating that the basis of the classification was at fault.

In place of this classification it was suggested by Doctor Brooks that one might be worked up on the basis of the cooling powers as shown by the katathermometer readings. (For description of the katathermometer, see the MONTHLY WEATHER REVIEW for September and December, 1920.) To the values obtained from the katathermometer readings obtained from Leonard Hill's "The science of ventilation and open air treatment,"[1] values were to be added or substracted to account for the factors of sunshine and evaporation.

After many attempts, an empirical formula was devised. For temperatures below 70° F.:

$$C_{\mathrm{m}}=\left(\frac{19.5-\vartheta_1}{603}+\frac{3.0+\vartheta_1}{222}\sqrt{v}\right)\left(0.10+\frac{0.40}{\sqrt{v}}\right)\vartheta_1+0.35+(2.0\times S) \tag{1}$$

For temperatures above 70° F.:

$$C_{\mathrm{m}}=(0.13+0.47\sqrt{v})\vartheta_1\frac{(8.5-\sqrt{v})}{11.8\times 10}+0.35+(2.0\times S) \tag{2}$$

This could be applied to data taken at any meteorological station of the Unitd States Weather Bureau (see preceding article by C. F. Brooks.)

Because of the pressure for time when these formulæ were finally derived, only one station was classified, namely, Los Angeles. (See fig. 1.) This station was taken in preference to others because if the oft-used expression, that Los Angeles has steady and almost Utopian climate, is true and the results upon the application of this formula indicated that the weather was seldom uncomfortable, then it might be inferred that the formula was of some value and consequently, of some potential use.

This curve also shows much steadier working conditions in the summer than in the winter. However, the curve by itself does not take into account the differences in the laboriousness of the task performed. Therefore at the right-hand end of the chart lines have been drawn, based on figures given in Leonard Hill's Science of Ventilation and Open Air Treatment, Part I, page 54, indicating the cooling power for a particular worker. Thus a man sawing wood would be uncomfortable nearly every day in the year, while a stone mason would be uncomfortable during the whole summer but could work with comfort during the winter months. A painter would not be uncomfortable at any time during the year if working in the shade, but would sweat on many days, both in summer and in winter, if he were painting in the sun. A shoemaker could work with comfort the year round provided he kept out of the sun; but during July and August conditions would be rather poor for work in the direct sunlight. According to these figures, a tailor has the most comfortable work of any of those given, for he is comfortable the year round when working in the shade and he would be uncomfortable only 43 days during the year even if he worked in the sun.

TABLE 1.—*Cooling powers (C_m) in millicalories per square centimeter per second for dry man at rest in the shade, Los Angeles, Calif.*[1]

Temperature	Wind velocity in miles per hour							
	2	4	7	10	15	20	25	30
°F.								
95	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5
90	.5	.6	.6	.6	.6	.7	.7	.7
85	.6	.7	.7	.8	.8	.9	.9	.9
80	.7	.8	.9	.9	1.0	1.1	1.1	1.1
75	.8	.9	1.0	1.1	1.2	1.2	1.2	1.3
70	1.0	1.1	1.2	1.2	1.3	1.4	1.4	1.5
65	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.8
60	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2
55	1.7	1.9	2.0	2.1	2.3	2.4	2.5	2.7
50	2.0	2.2	2.3	2.5	2.7	2.8	3.0	3.3
45	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.8
40	2.6	2.8	3.1	3.4	3.6	3.8	4.1	4.4
35	2.9	3.2	3.6	3.9	4.2	4.4	4.7	5.0
30	3.2	3.6	4.1	4.4	4.8	5.0	5.3	5.6
25	3.6	4.1	4.6	4.9	5.4	5.7	6.0	6.3
20	4.0	4.6	5.1	5.5	6.0	6.4	6.8	7.2
15	4.4	5.1	5.6	6.1	6.7	7.2	7.6	8.1
10	4.8	5.6	6.2	6.8	7.4	8.0	8.5	9.0
5	5.3	6.1	6.9	7.5	8.2	8.9	9.4	9.9
0	5.8	6.7	7.6	8.3	9.1	9.8	10.5	11.3

[1] Values in this table were computed from the following formulæ, then smoothed: For temperatures (°F.) 0°–70°, $C_m=\left(\frac{19.5-\theta_1}{603}+\frac{3.0+\theta_1}{222}\sqrt{v}\right)(0.10+0.40\ \sqrt{v})\theta_1+0.35$. For temperatures 70°–95°, $C_m=(0.13+0.47\sqrt{v})\ \theta_1[(8.5-\sqrt{v})\ (11.8\times 10)]+0.35$.

* Part of thesis prepared under the direction of C. F. Brooks and presented as a portion of the requirements for the degree Master of Arts in Geography, Clark University.

[1] Two parts. London, 1919, 1920.

DISCUSSION OF THE CURVES

The dotted curve (see fig. 1) represents the cooling power of a man seated in the shade. In this Los Angeles region, the range of the cooling power is only 2 millicalories per square centimeter per second, thus showing a remarkable steadiness of the weather. From June 19 to September 20, the range was only 0.6 of a millicalorie and the curve indicates that the cooling power for this long period of time was sufficient to keep a man comfortable. The curve averages a cooling power of 1.2 while the ordinary rate of metabolism is 1.1, thus the weather of Los Angeles is just a little more than sufficient to compensate for the heat evolved by metabolism, thereby insuring comfort.

The dot-dash line represents the colling power of a man seated in the direct sunlight. The factor of sunshine has been substracted. (See preceding article by C. F. Brooks, for discussion of this factor.) For this reason the curve is much more jagged, showing that the sun does not shine for the maximum possible period every day in this locality. A man seated in the sunlight would be uncomfortable practically every day during the summer and many days even in the winter, provided his rate of metabolism remains constant at 1.1 millicalories per square centimeter per seond.

The broken black line is the curve in which most of us would be interested, for it gives the cooling power for a man working in the shade. This curve was derived by adding to the cooling power of a man at rest the value $(0.035+0.098 \sqrt[3]{v}) (F-f)^{4/3}$; F being the vapor pressure at 36.5° C. and f the vapor pressure at noon each day. This factor evaluated the maximum possible loss of heat through evaporation of sweat, by a man working in the shade. The solid black line on the chart shows the cooling power for a man working in the sun, the factor for sunshine having been subtracted.

A word here may be necessary to explain Table 1 and Figure 2. The table is based on formula (1) for temperatures below 70° F., and formula (2) for temperatures above 70° F. The table was smoothed after its completion. Figure 2 was constructed by working out values from the formula: $H^1 = (.035 + .098 \sqrt[3]{v}) (F-f)^{4/3}$, and the results were put into this graphic form in order that they might be easier to read in the case of figures for which values had to be interpolated.

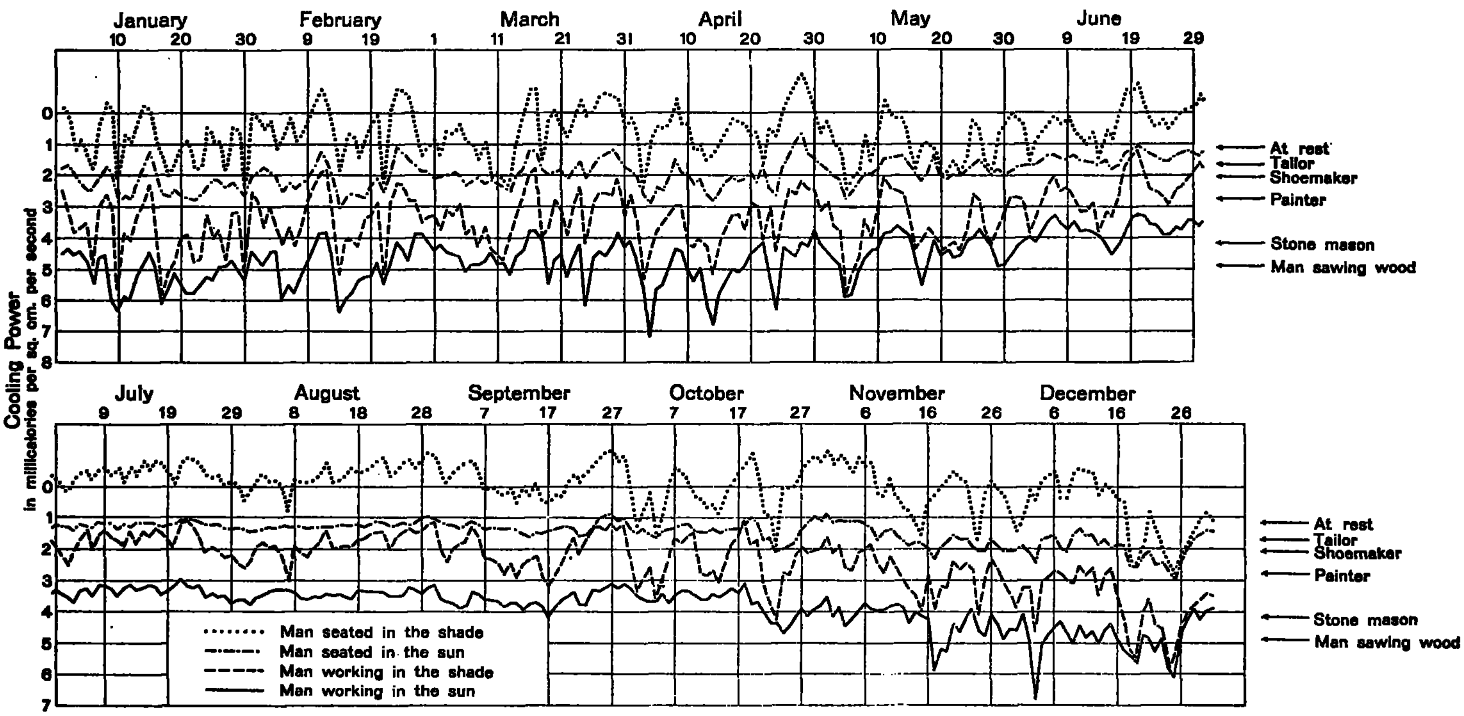

FIG. 1.—Cooling power of man under various conditions, in millicalories per square centimeter per second

CONCLUSION

From the excellent result of the application of the values obtained from the formulæ to data from Los Angeles, it is hoped that the result of this research will be used in connection with some plan by which working conditions can be made more pleasant. While the values given may or may not be of immediate use, yet they can be made the basis of further work. Possibly, when the values for enough cities have been charted, as Los Angeles has in this investigation, a basis for classifying the different sections of the United States could be made, which would be of great value to doctors and others interested in the relations of climate to health.

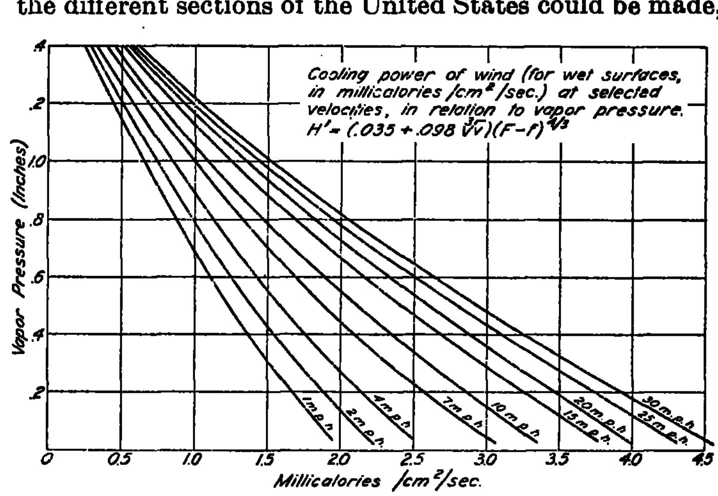

FIG. 2